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ABSTRACT

Although a major purpose of the Massachusetts Educational Assessment Program (MEAP) is to measure science achievement, it is also designed to provide information that can be used to improve curriculum and instruction. Student, teacher, and principal surveys were used to gather information on instruction, training, resources and other variables that were believed to affect science achievement. Schools that performed particularly well on the science portion of the MEAP assessment were visited and the entire elementary program observed. Commonalities between schools that did well on the science portion were determined. The results indicated: (1) in many elementary schools there is no science instruction at all, in others it is minimal; (2) there is a widespread lack of scientific equipment and little support for providing it; (3) many teachers lack the most basic scientific training; and (4) when science instruction does occur, it tends to stress content over process. The following recommendations are offered: (1) make hands-on scientific experience a major priority in teacher training; (2) provide science instruction on a daily basis in sessions long enough to allow students to become meaningfully engaged; (3) adopt the view that science instruction is not only important in itself but is an extension and reinforcement of the critical thinking skills that are taught both in language arts and mathematics; (4) anchor theory to experience through an instructional plan that begins with children's natural interest in the world; and (5) provide a variety of learning materials together with the support teachers need to use them effectively. (KR)

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CHAPTER 188

Massachusetts Educational Assessment Program

May 1987

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Science in the Elementary Schools

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Introduction

In April 1986 the Massachusetts Department of Education assessed the performance of all third grade children in the areas of reading, science and mathematics. The science portion of the test consisted of 169 items, divided into 10 different forms. Approximately two-thirds of those items were drawn from the National Assessment for Educational Progress. The remainder were newly developed for the Massachusetts assessment.

The percentage of correct responses for each item was transformed to scaled scores with a statewide average of 1300 and standard deviations of 100 points. Items were classified according to three major dimensions and scores were reported within these dimensions. For example, the *Content* dimension mainly refers to different topic areas, with the exception of Scientific Inquiry, which represented 50% of the total Content score. The *Context* dimension categorizes the items in terms of their application (personal, societal, scientific, technological). The *Cognitive Process* dimension categorizes items by the mental process that they are designed to measure (knowledge, comprehension, application, higher order).

The conceptual framework upon which the assessment was based was primarily the work of the Curriculum Advisory Committee. Not only did this committee develop the general plan of the assessment, but it reviewed all items, interpreted the results, and guided the Department in a growing recognition of the importance of science education. The strengths of the assessment are a tribute to the commitment of committee members.

Finally, before discussing our findings, it is important to acknowledge their limitations. Science achievement, including the category of Scientific Inquiry by which we defined process skills, was measured by a paper and pencil test with a limited set of alternatives. We did not ask students to handle material, organize data, formulate and test hypotheses. We asked them what they knew. We did not observe what they could do. On the other hand, we looked for evidence of understanding, of the ability to apply their knowledge to situations, and of reasoning in the areas of science. It is within this context that we are discussing scientific achievement among third grade children.

I. What is Taught? What is Learned?

Although a major purpose of the Massachusetts Educational Assessment Program is to measure achievement among schools in the Commonwealth, it is also designed to provide information that can be used to improve curriculum and instruction. To this end, we developed a series of student, teacher and principal questionnaires which asked for information on instruction, training, resources and other variables which were believed to affect science achievement. The following details some of our findings.

- ***In many schools children in third grade receive little or no science instruction at all.***

In over 20% of schools third grade teachers replied that they spent less than one hour a week on science instruction. This is *less than* 12 minutes a day. Yet, our analysis of the test results shows that time on task is an important factor in success, particularly on items that demand higher order thinking. We estimate an increase of between 35 and 40 points in science achievement scores for every additional hour per week spent on science instruction.

- ***There appears to be little consensus among teachers about what should constitute a third grade science curriculum.***

When the Department surveyed schools to determine the important areas to be included in the science assessment, few were considered important by more than 50% of the schools replying. Of the 53 areas listed, only two — *observing and comparing* and *nutrition* — were classified as "very important" by the majority of schools, while skills such as *measuring* and *organizing data* (using and constructing graphs, tables and charts) were considered "important" by only 35% and 22% of schools. In contrast, almost all of the reading topics received this rating.

- ***Science instruction shows little effect on children's science learning.***

Included in the teachers' questionnaire were 13 test items which represent different topics and types of thinking. Teachers were asked whether they had taught or reviewed the science needed to answer each item correctly. We then compared their responses to students' performance in their schools. (When two or more teachers from a school responded to the questionnaire, a scale was created which allowed us to produce a school response for each questionnaire item.)

Overall, there appeared to be little consensus on the topics included in the elementary school curriculum. Only three items elicited agreement by over 50% of the teachers. These were:

Item 74

What happens to a dead leaf that falls to the ground?

3 ○ The leaf will grow into a new tree.
25 ○ The leaf will stay the same unless it is burned.
66 ● The leaf will rot and become part of the soil.
6 ○ The leaf will grow into a small plant the next spring.

Item 77

Rain that freezes as it falls is called

6 ○ dew.
37 ○ snow.
53 ● sleet.
4 ○ fog.

Item 78

The oxygen we breathe is made by

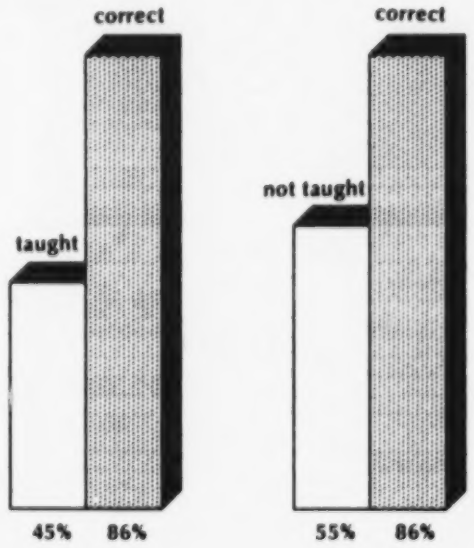
38 ○ the sun.
42 ● plants.
10 ○ volcanoes.
5 ○ other animals.

More interesting, however, there appeared to be little overall relationship between the extent to which topics were taught and student performance. That the majority of teachers indicated that students had been taught the information necessary to answer a particular item did not mean that most students answered the item correctly. Nor was the reverse true. For example, although only 45% of third grade teachers replied that their students had been taught the main function of the heart, 86% of students answered this question correctly. (See below, Item 79.) In contrast, although 40% of teachers indicated that they had taught their students about the nature of the scientific process (Item 75), only 26% of the students appeared to understand what scientists actually do. Over 60% of the students believed that scientists work only with facts or that a laboratory was a requirement for scientific experiments.

Item 79

What is the main function of the heart?

86 ● to pump the blood to all parts of the body
4 ○ to keep a person warm in winter by beating fast
6 ○ to store extra blood until it is needed
3 ○ to take waste food out of the blood



In addition to this general mismatch between instruction and performance, when we looked at individual schools we found little difference in success rate between those children whose teachers state that they *had* been taught the necessary information to answer the item correctly and those children who *had not* been taught the information.

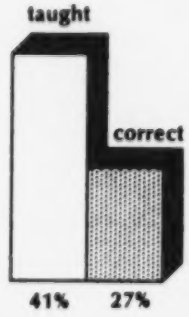
This suggests that children are not learning what they know about science from classroom instruction. Rather, their knowledge comes from their environment — television, books, magazines, conversations with adults and other children — and from their own efforts to make sense of the world around them. Unlike mathematics and reading, which are largely dependent upon formal instruction for mastery, science appears to be readily accessible. However, its very accessibility poses both a caution and a problem. The caution is that teachers cannot assume that their students are empty vessels, ready to be filled with scientific knowledge. Quite the contrary, children come to school with a great deal of knowledge about the world, as well as with sometimes erroneous notions about its underlying structure. The problem is that these notions, however erroneous, are not easily dislodged and can often impede any real scientific understanding in later years. Effective teaching has to start with the children themselves — what they know and how they understand the world.

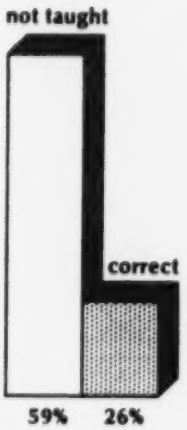
This potential for misconception is not confined to scientific laws. It extends to perceptions about science itself. For example, Item 75 illustrates a common misperception of the nature of science that can have implications for later attitudes. If students continue to believe that science is an elitist field, divorced from everyday life, or that the scientific process is closed, a search for definitive answers, then it is no wonder that older students fail to see science as an area that has relevance to their lives. Yet, this understanding of the nature of science is not readily attained from general sources. It is more likely to come from carefully structured discussions that take place between the teacher and the class. In this sense, success on this item should be directly related to instruction.

Item 75

Which statement about scientists is TRUE?

26 ● When scientists solve one problem, they often find new problems.
30 ○ Scientists work only with facts, not with guesses.
9 ○ Scientists know everything about what makes up things.
32 ○ To do an experiment, a scientist needs a laboratory.





- ***The emphasis of science instruction in the schools is on content rather than on scientific inquiry.***

On the teacher questionnaire, factual items were more often recognized as appearing in the curriculum, with far fewer teachers responding that they had taught the science necessary to answer questions involving application or comprehension.

Forty-three percent of the students stated that they had not made a chart or graph during science or math class during the previous month.

Forty-eight percent of the students stated that they had not measured or weighed anything during the same period.

Fifty-one percent of teachers stated that they relied primarily on textbooks for their instruction.

- ***Material for scientific activities is lacking in many schools.***

Fifty-five percent of third grade teachers stated that they had very little "hands-on" material for their use in teaching science.

Approximately 50% of the principals surveyed spent less than $100 per annum on the purchase of new science equipment or for consumable science supplies.

Approximately 10% of schools state that they have little or no resources and teach little or no science.

In our analysis of the test results, we found that science achievement was strongly related to the availability of equipment. The difference in scores between schools that had all the equipment that teachers wanted and those that had very little was as much as 100 points. In addition, when equipment is plentiful, schools that rely primarily upon science kits for their instruction generally scored higher than those for whom texts were the primary mode of instruction. This difference in achievement was particularly apparent among those items that called for factual information and comprehension.

Among schools using kits, approximately 38% scored above 1350 in Content Knowledge. In contrast, only 6% of schools relying on textbooks for instruction achieved this level of performance. However, the simple dichotomy between different modes of instruction (kits versus text) is confounded by the relative availability of equipment associated with each. Among teachers relying primarily upon texts, over 60% stated that they had very little equipment, in contrast to 17% of those using kits. Schools reporting lack of hands-on material invariably scored below the state average, regardless of time spent on science instruction or the actual mode of instruction.

- ***Many teachers lack the training necessary for effective science instruction.***

Certification requirements for preparation in science are ill-defined at the elementary level. Furthermore, colleges and universities offering Elementary Teacher Certification often do not emphasize the importance of science education. Science training is sometimes optional at these schools and in most cases inadequate.

Twenty percent of third grade teachers state that they have not had any kind of training in science education, including undergraduate and in-service courses.

- ***There is a lack of support for elementary school teachers responsible for science instruction.***

Although 20% of schools have a science curriculum consultant, these consultants work mainly with students rather than with teachers. When this happens, students tend to have *less* science instruction, possibly because the classroom teacher no longer feels responsible.

II. The Schools

Why did some schools perform particularly well on the science portion of the assessment? Was it the result of a particular curriculum, an instructional approach, or a philosophy of education? Is there anything that they can show other schools to improve their own instruction?

Although some patterns emerged from our analysis of the student, teacher and principal questionnaires, we decided that analysis alone could not give us the answer. Numbers could tell us what was lacking. They could not tell us what worked. We had to look at the schools themselves, to observe them.

In our search for superior performance we looked for indications that science teaching was particularly effective: schools that scored higher in science than in the math and reading portions of the assessment; schools that were large enough to minimize the effect of chance or the characteristics of a particular class; schools that had scored significantly above what might have been predicted by the background factors of their students (i.e., their Comparison Score Band). We looked at different kinds of communities and chose five schools that met our criteria. One was from a large urban district, two were suburban, one was an older school in a rapidly growing urban community, and one was situated in a relatively rural area.

Once we identified these schools, we visited them to observe and investigate, not just their third grade classes, but their entire elementary science program — both intended and implemented. At each school we asked, what is special here for us to learn from? What are the instructional features that other schools might consider adapting to their own programs? Some of the results of our observations follow.

. . . . . .

A first grade class in an urban school: most of the children work at their desks. Three boys stand at a table in the back of the room pouring water from one container to another — taking off the chill. On the table stands an aquarium. Soon they will be changing the water in that aquarium. Right now, they are observing its occupants.

"I think it's hiding under a rock cause it's going to have babies."

"I saw it take a bite."

The science support teacher and some other children join the group.

"I see the other newt right there." A boy points and then gently lifts the newt. *"Look how big it's getting. That's why I think she's going to have babies."*

Another boy lifts the other newt out and looks at both. *"That one is bigger."*

Now the teacher and the other children come up to the table. The science teacher asks, *"If she does have babies what do you think they will look like?"*

A child answers, *"Like little black beads in jelly."*

Another asks, pointing to a small container, *"Shouldn't we put the eggs in there? She might eat them."*

The teacher says that each morning the children check on the newts. Since the newts' arrival the children have been bringing pictures of other animals to put on the bulletin board.

. . . . . .

A third grade class in a country suburb: two rows of desks are arranged in a semi-circle. In the center is a demonstration table. A projector screen is pulled down over the blackboard and the teacher is using it to review a list of facts about soil before beginning an experiment.

"Why is soil important?"
"Why do we grow plants?"
"What does good garden soil contain?"
"What is decay?"
"If you put soil in a pot and put it on a burner and heated it, what would happen?"
"When it rains, water disappears into the ground. Who can tell why?"

With the final question, the teacher pours water in a dish. *"I'm going to put a sponge in this dish. Watch the way the sponge absorbs water."*

The children watch intently, letting out an *ooh* as the sponge takes up the water.

The teacher waits until the water has been absorbed completely, then asks, *"Why does the sponge absorb water?"*

The children offer a variety of explanations. One suggests, *"Because of the air holes."*

The teacher then makes the analogy to soil: *"Do you think the different kinds of soil will hold different amounts of water?"*

The children speculate why this might be so. *"Humus has lots of animals and stuff. That takes up a lot of space. There isn't room for water."*

"Sand would hold a lot of water."

The teacher switches on the projector. *"We're going to find that out."*

She projects a description of the investigation — the materials needed and the procedure. She then lays out the necessary equipment —

three coffee cans with holes punched in the bottom, three clear jars, a measuring cup and three bags of soil (sand, garden soil and humus from the greenhouse of the father of one of the children). Three children are chosen to help. The others watch as they fill each of the cans with a different kind of soil, place jars under them and then pour water into each. The children look at the amount of water that collects in each jar and answer their teacher's questions about it. Then she gives them a worksheet.

"I have a worksheet for you to show me whether you understood our investigation. Next time we'll found out about what kind of plants grow in different soils."

• • • •

Two second grade classes in an older school in a rapidly growing small city: both classes have read together the chapter in the text on magnets and now the children are using magnets in the classroom. First, the teacher demonstrates with two horseshoe magnets.

"If I spilled pins would it be as easy to pick them up as when we spilled paper clips?"

The children think not. *"You might hurt yourself,"* suggests one child.

The teacher agrees and goes on: *"Magnets are powerful and useful. We could use one to pick up the pins."* She holds up the horseshoe magnet. *"Does anyone know what this is called?"*

"It's shaped like a horseshoe," observe the children.

The teacher next shows them another horseshoe magnet which is heavier, thicker and almost closed at the bottom. She then shows them a bar magnet and asks if anyone knows what it is called. She shows them a round magnet — *"a refrigerator magnet,"* one child says. She shows them how it picks up a paper clip.

She then explains, *"When you put it near something made of iron it will stick."*

The children are intrigued. *"Try the chalkboard,"* suggests one.

The teacher tries. *"No, I don't think so,"* she says as she holds the magnet to the board.

The teacher now gives each pair of children a small bar or round magnet. She gives them a piece of paper and asks them to make two columns headed STICKS, DOESN'T STICK. *"List the things the magnet will stick to and the things it won't stick to."*

The children go around the room putting the magnets to desks, chairs, pencils, sharpners, the brass door handle.

"It doesn't stick on a door handle," observes one child.

"Yes, it does," counters another as she puts the magnet underneath the knob and it sticks to a screw which she did not see. A boy watches her and as she leaves to write door handle, he goes to the knob and looks at it carefully. He places the magnet on the knob and then on the screw. He writes "screw of door handle" on his paper and smiles as if he has a secret.

After a while, the children are told to sit in their seats. The teacher makes two columns on the board and writes, MAGNETS STICK. MAGNETS DON'T STICK. The children give the names of the objects that stick and the teacher writes them.

III. Commonalities

If we had hoped to find a common teaching style or philosophy among these schools, we were mistaken. The classes differed in the amount of scientific knowledge or enthusiasm among teachers, their sources of curriculum, and their students. None the less, there were some commonalities.

- ***Science instruction is taken seriously.***

In these schools science is not optional, an enrichment course to be tacked onto the fundamentals, but it is taught throughout the elementary school on a regular basis. Science teaching begins on a relatively informal basis in kindergarten where children have many experiences with plants, animals, weights, measures and changing substances. It is carried along with increasing time allotment throughout the grades. In grades one and two approximately an hour a week is devoted to science instruction on a regular basis, and this is usually increased to more than two hours by grade three.

- ***Science instruction follows a well-structured course of study.***

All schools follow a well-structured course of study, with a broad range of overlapping topics. In three of the schools, science textbook series effectively determine the curriculum framework. Teachers follow these for both content and sequence of instruction. In addition, the texts offer suggestions for supplementary materials and activities. In these schools texts are not synonymous with "received knowledge" but act as a catalyst for activities and discussion.

In the other schools an independent curriculum exists. In one, the curriculum has been drawn up by the district science staff. Although textbooks are used regularly by the teachers, these are supplemented by staff-written lesson units. Possibly because of the variability inherent in a large school system, the curriculum is highly structured. Each grade has a monthly objective plan based on the curriculum objectives and the text. These consist of supplemental instruction guides for specific chapters and units, suggesting discussion questions and activities requiring manipulative materials. The result is a carefully detailed program of instruction using textbooks, work papers, tests in scientific knowledge and supplementary experiences, such as caring for plants and animals, which enlarge the children's knowledge and excite their interest.

The other school, which relies heavily upon kits for its science instruction, uses a teacher-developed written curriculum as its guide. This contains sequences of topics, activities, resources built around SCIS materials, and sources for supplemental material.

In all cases, instruction reflects the attention that is given to the organization of the curriculum, to planning sequential activities, to building on past experiences and to giving children many opportunities to talk, question, write and express their thoughts.

- ***Adequate resources are available.***

None of the schools that we visited appear to lack for resources and all enjoyed open spaces with a variety of plants and animals. In only one school did the teachers say they were lacking "hands-on" equipment. Here, they rely upon supplementary and teacher-developed materials, as well as upon textbooks.

- ***Support is available for staff.***

In the schools we visited resources are not confined to tangible materials. All can rely upon human resources for support.

In one urban school, teachers can turn to a specialist who had been assigned by the district to assist them in their science teaching. Although the classroom teachers are primarily responsible for the teaching of science, this science support teacher visits each classroom approximately once a week to introduce a new animal or plant, to check on equipment, to talk with the teacher about progress and to demonstrate an occasional lesson. The district supports a corps of such specialists who spend a day a week in each school and work together to develop materials and activities.

In the suburban and rural schools, teachers turn to parents, to outside environmental centers or to local science museums for help. In one school the teacher sends a weekly letter to parents listing the activities for the week and asking for volunteers. Since parents of children in this class know what is going on in the classroom, there is more talk at home and more reinforcement of what is learned in school. In other schools, we heard of visits from a father who was a veterinarian, a mother who was a nutritionist. Such schools asked parents to help children relate the science that they were learning to the larger social context.

- ***Science is integrated into the language arts curriculum.***

There are two aspects to science. One is empirical, activity-oriented, involving the collection and quantification of data. The other is more theoretical, involving the content and basis of what is known. For the first, mathematical skills are necessary. The latter relies more on language.

As a group, the schools that we observed generally stress the latter. Consequently, their science instruction is closely linked to instruction in the language arts. For example, in those cases where texts are the primary vehicle for the curriculum, students read aloud from these on a regular basis. In all cases, however, reading is an important component of science instruction. If children did not read together, they read separately from fact sheets, source books and worksheets.

They also write — again, in a range of forms, depending upon the grade and the oreintation of the particular class. Sometimes it is as simple as filling in the correct term; a recurrent feature of instruction, however, is individual topic booklets in which children record the results of their research.

On the other hand, in the kindergartens visited, children get many hands-on experiences with varied materials that develop concepts which may help them in their later understanding of textual material. In these kindergartens, processes in developing science understanding — such as observing, measuring, estimating, trial and error — are part of every child's life at school.

- ***Discussion plays an important part in instruction.***

In all of the classrooms there was a deliberate attempt to involve students in discussion, to encourage them to reflect and to call their attention to significant facts and concepts.

Teachers used pictures, charts and films, as well as class experiments and demonstrations as opportunities for sharing ideas, hypotheses and information. Not only did this approach help in science instruction, as teachers were better able to understand their students' understanding and perceptions, but it is also an important opportunity to improve listening, speaking, and critical thinking skills that are basic to successful education.

IV. Conclusions

Secretary of Education William J. Bennett, in his report on elementary schools, discusses science instruction in these terms.

> *"There is probably no other subject whose teaching is so at odds with its true nature. We have come to think of science as a grab-bag of esoteric facts and stunts. Worse, we have also given students the impression that science is a dry and arcane matter gleaned solely from the pages of a textbook . . . . If science is presented like this, is it any wonder that children's natural curiosity about their physical world turns into boredom by the time they leave grade school — and into dangerous ignorance later on? . . . But as a 'hands-on' adventure guided by a knowledgeable teacher, it can sweep children up in the excitement of discovery. Taught by the regular classroom teacher, it can illustrate the point that science is for everyone — not just scientists."*

The Secretary's analysis reflects a common concern among educators: that within the primary classroom, science's primary goal of discovering and understanding the laws that rule our universe is trivialized into the need for memorizing a catalogue of facts. The stress that he places on "hands-on" activities for reversing this situation is also familiar. Most science educators turn to the curriculum studies of the 1970's to show the effectiveness of an activity-oriented classroom in achieving an understanding of both content and process. More important, it is these activities that develop an attitude toward the physical world that is based on curiosity, a willingness to experiment, to question, to try — what we loosely call a problem-solving approach.

Secretary Bennett refers to an ideal. To reach that goal is not as simple as turning from texts to activities in our science instruction. In our study of the assessment results, we found a network of problems that must be faced.

- *We found that in many elementary schools, there is no science instruction at all. In others, it is minimal.*

- *We found that there is a wide-spread lack of materials and support for using materials.* We found that half the schools in the state allocate little or no money for scientific equipment or supplies. We also found equipment packed away in boxes, not used because of lack of direction, support or training.

- *We found that many teachers lack the most basic scientific training.* We infer that most lack the confidence and basic scientific knowledge to create meaningful scientific experiences for children. We suspect that they themselves may reflect the negative attitudes about science that are so prevalent among older students.

- *We found that when science instruction does occur, it tends to stress content over process, ignoring science's relationship to the more practical world of mathematics.*

We do not suggest that schools throw out their textbooks in favor of kits. In the absence of any other support, a well-designed textbook is critical. It covers a

range of topics, distills the basic concepts, gives the teacher guidance in presentation. In short, it functions as a pseudo-curriculum for the teacher in an area where he or she may feel ill at ease or ill-prepared to teach. However, it cannot stand alone, particularly in an area that is fundamentally embedded in the physical world.

RECOMMENDATIONS

For elementary science instruction to be effective, we strongly recommend:

- ***Hands-on scientific experience* for teachers *should be a major priority for pre-service and in-service training.*** Teachers who lack understanding of science are not likely to be able to develop scientific concepts in their students. Nor can we expect teachers to encourage students' scientific explorations if they themselves feel uncomfortable or incompetent in such an environment.[1]

- ***Sufficient time should be allocated to science instruction on a daily basis and in sessions long enough to allow students to become meaningfully engaged in activities and see them through to completion.*** If science teaching is to be more than the memorization of facts, children need the opportunity to explore, investigate and discuss the scientific phenomena in the world around them. Children come to science classes with ideas and interpretations that have formed as a result of everyday experiences in all aspects of their lives: through practical acitvities, conversation, the media. It takes time for them to understand and articulate their own views, to consider alternative views and to reconcile conflicts.

- ***Science instruction should be viewed not only as important in itself, but as an extension and reinforcement to the critical thinking skills that are taught in the language arts and the more practical inquiry skills of mathematics.*** By challenging children to make sense of their world, science can supply an inviting context for writing, discussing and evaluating activities. At the same time, it demands the more practical skills of counting, measuring, classifying and graphing that are essential to mathematical understanding.

- ***Instruction should reflect a well-structured curriculum which extends beyond textbooks to include activities and discussions.*** While we argue that science cannot be thought of as a collection of facts, neither should it be regarded as a collection of activities. Children do not necessarily see the need for a coherent view as long as *ad hoc* interpretation and predictions work quite well in practice. It is the teacher's role to anchor experience to theory through an instructional plan that begins with children's natural interest in the world.

- ***Teachers should be supplied not only with a variety of learning materials, but with administrative and curricular support.*** Although science teaching demands physical resources at all levels, in the early years, particularly, children need physical evidence for the theories that they must learn. On the other hand, materials in themselves are useless unless teachers are given the support necessary to use those materials effectively. Science curriculum specialists or

coordinators should handle several responsibilities: the maintenance of equipment; assistance in using commercial material; generating ideas for activities and ways of using everyday objects or materials; support of teachers improving their science instruction. This implies an administration that views science as a vital part of the elementary school experience and as an effective reinforcement to other areas of learning.

[1] Footnote: A national study reports that only 22% of Grade K-6 teachers believe that they are well qualified to teach science.

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